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EXPERIMENTAL BROADBAND ULTRASONIC TRANSDUCERS USING PVF2 PIEZOE--ETC(U)
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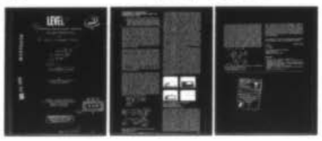

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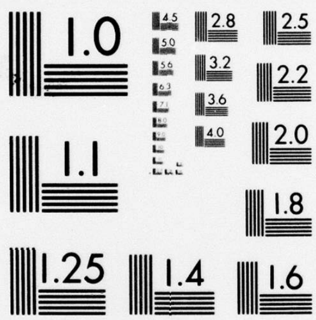


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# EXPERIMENTAL BROADBAND ULTRASONIC TRANSDUCERS USING $PVF_2$ PIEZOELECTRIC FILM

by


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# EXPERIMENTAL BROADBAND ULTRASONIC TRANSDUCERS USING $PVF_2$ PIEZOELECTRIC FILM

*Indexing terms: Piezoelectric transducers, Thin-film devices*


Broadband ultrasonic transducers using $PVF_2$ piezoelectric plastics films, combining efficient transduction with extremely wide and uniform passbands, have been fabricated using very simple procedures without any critical tolerances. Frequency spectra of impulsed transducers using films of 25 and 50 $\mu$m thickness, centred at 10 and 5 MHz, respectively, are shown.


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*Introduction:* Broadband ultrasonic transducers are important for a variety of purposes, including signal processing where large bandwidth is needed for high data rates, time-domain spectrometry where large bandwidth is needed to handle short pulses, and ultrasonic imaging where operation over a range of frequencies is necessary for obtaining optimum response from a variety of objects. We find that very broadband transducers can be easily constructed using poled $PVF_2$ films,[1,2] using procedures which are much simpler than those involved in the construction of standard types using p.z.t. ceramic elements, and having bandpass characteristics which are broader and more uniform than commercial p.z.t. transducers.

*Description of experimental transducers:* The new transducers were formed by epoxy bonding a small piece of poled $PVF_2$ film to a brass rod. A sketch of a typical unit is shown in Fig. 1*a*. The brass rod serves as an acoustic backing, which acoustically loads the back side of the $PVF_2$ film, as well as providing mechanical support for the film. The brass rods for the present transducers are 25·4 mm in diameter, of arbitrary length and serve as a convenient handle for holding and positioning the transducer. Available transducer thicknesses of both 25 and 50 $\mu$m were used to radiate rectangular acoustic beams of the approximate dimensions $6{\cdot}4 \times 19{\cdot}2$ mm. The choice of the rectangular shape in this case was arbitrary and a change to any other shape would represent only a trivial modification.

*Measured transducer characteristics:* Experimental models of the above transducers have been operated in water, in both reflection and transmission modes, to determine bandwidth and insertion loss. In this operation, the device of Fig. 1*a* is simply submerged directly in the water tank, without any covering over the $PVF_2$ surface. Passband characteristics were determined by impulsing the transmitting transducer, and observing the output of the receiving transducer on a spectrum analyser. In the transmission mode, separate transducers were used for transmitting and receiving with sufficiently close spacing (25·4 mm) to avoid effects of diffraction and water attenuation. In the reflection mode, a single transducer performed as both transmitter and receiver, with the acoustic beam reflected from a glass surface located 12·7 mm from the transducer.

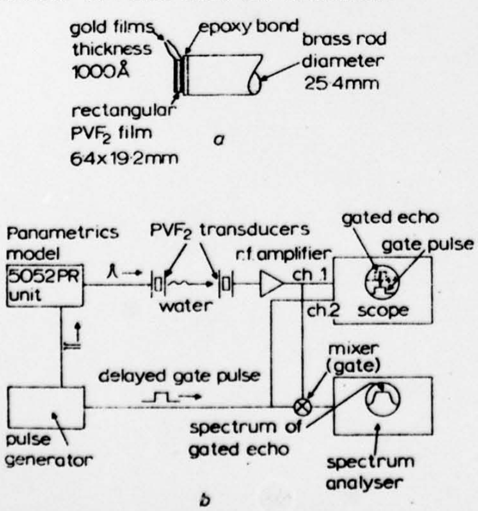


**Fig. 1** *System for spectrum analysis of echoes in water*
*a* Schematic of $PVF_2$ transducer
*b* Block diagram of system

A block diagram of the experimental setup is shown in Fig. 1*b* for transmission-mode measurements. The system uses a standard Panametrics Model 5052 PR unit which delivers a very short electrical pulse to energise the transmitting transducer. The spectrum of the excitation pulse was observed on the spectrum analyser and found to be essentially flat between d.c. and 20 MHz. An electronic gate selects the desired echo from the output of the receiving transducer, separating it from the direct electromagnetic feedthrough pulse and other pulses in the multiply reflected acoustic pulse train. The selected echo is amplified and, along with the gate pulse, displayed on a 2-channel oscilloscope, and the spectrum of the echo is displayed on a spectrum analyser.

The spectra of the first echo for various transducers are shown in Fig. 2. The spectrum of a commercial 14 MHz transducer (Fig. 2*a*) is shown for purposes of comparison. The response of the 25 $\mu$m $PVF_2$ transducers (Fig. 2*b*) is essentially flat from zero frequency to 20 MHz. The response of the 50 $\mu$m $PVF_2$ transducers (Fig. 2*c*) is flat within 10 dB from 1 to 10 MHz. These are 'round-trip' spectra, i.e. the spectra of the pulses after experiencing two transductions. The round-trip insertion loss has the same order of magnitude as the commercial p.z.t. unit of Fig. 2*a*.

The lateral dimensions of the $PVF_2$ films are large compared with their thickness, so that the films vibrate in the thickness extensional mode. However, the observed thickness resonance frequencies correspond approximately to quarter-wave film thickness, rather than halfwave thickness as for unloaded $PVF_2$ resonators,[3,4] because the impedance of the backing material is greater than that of the transducer. The ratio of the acoustic impedance of the brass backing to that of $PVF_2$ is approximately 11, and a ratio greater than about 1·4 is sufficient to shift the resonance frequency down to the vicinity of the quarter-wave frequency.[5] The quarter-wave frequencies cannot be obtained accurately from the spectra of Fig. 2 because the thickness of the adhesive bond is not accurately known. However, it is comparable to that of the $PVF_2$ film, and, in any event, its effect would be to shift the resonance frequency further downward, to less than half the frequencies of unloaded films, and this is consistent with the results of Fig. 2.

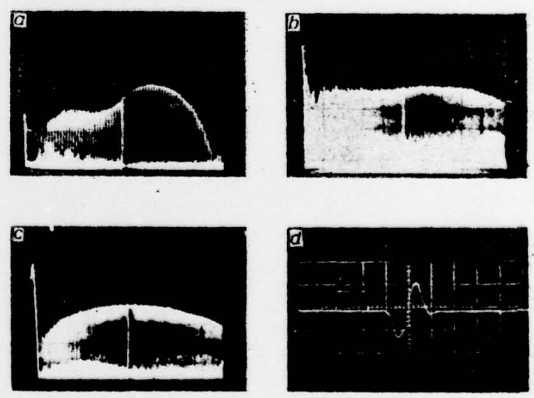


**Fig. 2** *Measured transducer characteristics*
*a* Spectrum of p.z.t. transducer
*b* Spectrum of 25 $\mu$m $PVF_2$ transducer
*c* Spectrum of 50 $\mu$m $PVF_2$ transducer
*d* Impulse response of 50 $\mu$m $PVF_2$ transducer

Analysis of the transient response of a transducer may be based on the assumption that, if an electrical impulse is applied, four ultrasonic pulses are generated, two at each face.[6] For each of these two pairs of stress waves, one of the waves travels into the transducer and the other travels into either the water loading or the backing medium (Fig. 3). The resulting two pulses within the transducer travel backwards and forwards and are reflected and transmitted at the transducer faces. The degree of reflection depends on the characteristic impedances of the transducer, the loading and the backing medium. With our transducer configuration of brass–$PVF_2$–water, the pulse generated at the $PVF_2$–water interface and travelling into the transducer is approximately ten times larger in magnitude than the corresponding pulse generated at the brass–$PVF_2$ interface (because of the high

impedance of brass relative to $PVF_2$). Thus the output stress consists essentially of two stress waves, one launched from the front face directly into the water and the other launched from the front face into the backing and reflected from the back face into the water. The latter wave suffers little reflection at the $PVF_2$–water interface, because the acoustic impedances of $PVF_2$ and water are relatively close. The two stress waves are separated by the round-trip time in the transducer. This pair of stress waves is detected by a second transducer of the same thickness as the transmitting transducer as a bipolar pulse (Fig. 2*d*). The fact that the detected pulse is approximately bipolar indicates that acoustic energy generated within the $PVF_2$ transducer is efficiently coupled to water. Had it been otherwise, the detected pulse would have many cycles, owing to multiple reflections inside the transducer.

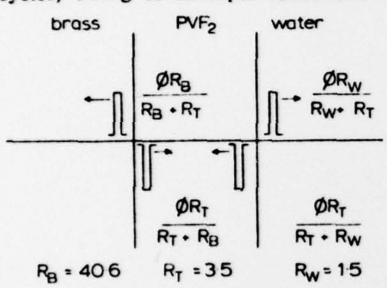


**Fig. 3** *Physical interpretation of response of piezoelectric transducer to electrical-impulse input*

$\phi$ = stress/unit input voltage
$R$ = relative characteristic acoustic impedance

This is consistent with other measurements[3,4] made on $PVF_2$, which show that the acoustic impedance of $PVF_2$ is close to that of water, as shown in Fig. 3. This is important in providing the clean pulse shown in Fig. 2*d*, in contributing to the very broad bandwidth of the transducer and in compensating for the lower piezoelectric coupling coefficient of $PVF_2$ compared with that of p.z.t., thus maintaining high transducer efficiency.


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